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Initial Performance of Turkish Red Pine (Pinus brutia Ten.) and Maritime Pine (Pinus pinaster Aiton) Afforestation in Izmir, Türkiye*

Kızılçam (Pinus brutia) ve Sahil Çamı (Pinus pinaster) Ağaçlandırmalarının İlk Performansı, İzmir-Türkiye

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Abstract

The success rate of pine afforestation in Mediterranean countries decreased sharply in recent years, highlighting the critical need for selecting suitable tree species to ensure ecosystem sustainability and afforestation success. This study assesses the initial afforestation performance of two ecologically and economically important pine species in Türkiye under Izmir conditions, aiming to guide future semi-arid zone afforestation and restoration projects. The survival and growth of Turkish red pine (*Pinus brutia* Ten.) and maritime pine (*Pinus pinaster* Aiton) seedlings planted on northern and southern aspects of an experimental plot in Izmir-Buca were compared one and two years after planting. Two-factor ANOVA analysis revealed that Turkish red pine seedlings exhibited a 72% higher survival rate after two years than maritime pine seedlings. Diameter growth varied by species and aspect, with Turkish red pine showing similar performance on both aspects, while maritime pine showed significantly lower performance (18%) on the southern aspect. Regardless of species, crown growth was considerably better in northern aspects, consistent with findings on superior soil moisture retention. These results indicate that Turkish red pine possesses greater drought tolerance than maritime pine under climate change conditions and is more suitable for semi-arid regions. Further research with different origins and locations over an extended period is recommended.

Keywords: Adaptation, Climate Change, Drought Tolerance, Forest Restoration, Mitigation

Özet

Son yıllarda, Akdeniz ülkeleri çam ağaçlandırmalarında başarı oranı keskin bir şekilde düşmektedir. Bu, ekosistem sürdürülebilirliğini ve ağaçlandırma başarısını sağlamaya yönelik uygun ağaç türlerinin seçiminin önemini vurgulamaktadır. Bu çalışma, Türkiye'de ekolojik ve ekonomik açıdan önemli iki çam türünün İzmir koşullarındaki başlangıç ağaçlandırma performansını değerlendirerek gelecek yarı kurak bölge ağaçlandırma ve restorasyon projelerine rehberlik etmeyi amaçlamaktadır. Çalışmada İzmir-Buca'da yapılan bir ağaçlandırma sahasında, kuzey (KB) ve güney bakılarına (GB) dikilen kızılçam (*Pinus brutia* Ten.) ve sahil çamı (*Pinus pinaster* Aiton) fidanlarının birinci ve ikinci yıl yaşama oranı ile büyümesi karşılaştırılmıştır. İki faktörlü ANOVA analizi, kızılçam fidanlarının iki yıl sonra sahil çamı fidanlarına göre %72 daha iyi yaşama oranı sergilediğini ortaya koymuştur. Çap büyümesi türe ve bakıya göre farklılaşmıştır. Kızılçam KB ve GB'da benzer performans gösterirken, sahil çamı çap büyümesi GB'da anlamlı düzeyde düşmüştür (%18). Türden bağımsız olarak, tepe büyümesi KB'da anlamlı düzeyde artmıştır. Bu bulgular, toprak nemi bulgularıyla da tutarlılık göstermiştir. Sonuçlar, kızılçamın iklim değişikliği etkileri altında sahil çamına kıyasla kuraklığa daha dayanıklı olduğunu ve yarı kurak alan ağaçlandırmaları uygun bir tür olduğunu göstermektedir. Gelecekte, farklı orijin ve sahaların kullanıldığı daha uzun süreli araştırmaların da yapılması önerilir

Anahtar Kelimeler: Uyum, İklim Değişikliği, Kuraklık Toleransı,Orman Restorasyonu, Azaltım

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1. Introduction

Two-thirds of Türkiye experiences a semi-arid climate (Ayan et al., 2021). Global climate change exacerbates this aridity through higher intensity and frequency of peak weather occurrences, including heatwaves, wildfires, floods, and prolonged droughts (Afzal et al., 2016; HLPE, 2017; Yıldız et al., 2022; Laaribya et al., 2023; Özel et al., 2023). Projected temperature increases of 1-6°C in Türkiye between 2016 and 2099 (Demircan et al., 2017; Çalışkan et al., 2023) will particularly stress water resources in the Mediterranean basin, leading to expanded arid zones (Feng & Fu, 2013; Türkeş et al., 2020; Bağçacı et al., 2021; Laaribya et al., 2023). Studies link climate change to widespread forest mortality and shifts in tree species distribution (Vacek et al., 2023; Çalışkan et al., 2023).

Turkish red pine (TRP, *Pinus brutia* Ten.) and maritime pine (MP, *P. pinaster* Aiton), members of the *Pinus* subsection *Pinaster*, thrive under diverse ecological conditions in the Mediterranean basin (Klaus, 1989; Richardson, 1998; Grivet et al., 2013). They are both ecologically (biodiversity, ecosystem services) and economically (timber, non-timber products) significant fast-growing species (Neyişçi, 1993; Boydak, 2004; Şener, 2004; Boydak et al., 2006; Fernandes and Rigolot, 2007; Balekoğlu and Ertaş 2016; Guignabert et al., 2018; Fidan et al., 2022; Manjarrez et al., 2024). Their adaptation to drought and fire in Mediterranean ecosystems is well-documented (Tapias et al., 2004; Grivet et al., 2013; Barrio-Anta et al., 2020). TRP is reported to show optimal natural regeneration in Mediterranean ecosystems, including those in Türkiye (Neyişçi, 1993; Boydak, 2004; Boydak et al., 2006; Kavgacı et al., 2016; Baykara and Eşen, 2024). Afforestation with MP has been reported to successfully restore degraded sites in Türkiye (Şener, 2004) and Greece (Karamanoli et al., 2017).

Afforestation is crucial for biodiversity conservation, microclimate improvement, soil fertility enhancement, erosion and desertification control, water resource management, and wood and nonwood forest production (Cortina et al., 2011; Boydak and Çalışkan, 2021; Çalışkan and Boydak, 2017; Doelman et al., 2020; Yıldız et al., 2022; Laaribya et al., 2023). Afforestation also mitigates the complex effects of drought and restores vulnerable ecosystems impacted by climate change (Scarciglia et al., 2020). In recent years, afforestation efforts in Türkiye have mainly focused on arid and semi-arid regions that have suffered degradation or fire damage (Yıldız et al., 2022). Careful species selection is critical for success in these arid and semi-arid regions (Boydak and Çalışkan, 2017; Deligöz and Gencer, 2021).

Although no significant problems have been reported in Turkish forestry with natural and artificial regeneration of TRP and MP in arid and semi-arid areas in Mediterranean ecosystems, the reforestation success of these species under changing conditions with climate change (e.g., more frequent and effective dry periods and forest fires) is a significant question mark (Baykara and Eşen, 2024). Annual precipitation dramatically decreased in recent years for the Aegean Region of Türkiye: The region's total annual precipitation between 1991 and 2024 averaged 605 mm. However, it showed a substantial (22%) reduction in 2024 (AFAD, 2025). A recent study comparing the natural regeneration of TRP in burned and unburned areas in Izmir reported that fire did not affect natural regeneration density. However, the subsequent drought with fire effects significantly reduced seedling diameter growth in burned areas (Baykara and Eşen, 2024).

Fernandes and Rigolot (2007) reported that although MP is a drought-tolerant species, wildfires accelerated by climate change threaten the spread of this species. Similarly, with changing climatic conditions in Spain, significant failures in the regeneration and growth of pine species have begun to be observed (Fernandez-Garcia et al., 2019; Romeo et al., 2020). Similar results are also reported in Turkish Mediterranean pine forest ecosystems, and there are concerns about whether forest regeneration rates will decline and even turn into deforested areas (Fernandez-Garcia et al., 2019; Romeo et al., 2020).

The choice of forest tree species to be used in afforestation in such areas is of great importance (Çalışkan and Boydak, 2017; Deligöz and Gencer, 2021). This study investigates how climate change affects these two pine species in terms of afforestation at the scale of Izmir, especially during severe drought and addresses a critical issue of species selection for afforestation in semi-arid regions facing climate change. Furthermore, this study aims to evaluate the initial sustainability of pine ecosystems and the overall reforestation success of the pine species and select species more resilient to these impacts. Therefore, this study aims to guide future semi-arid zone afforestation and forest restoration efforts in practice and help adaptation and mitigation to climate change impacts.

2. Materials and Methods

The study is conducted in the afforestation site with TRP and MP located in compartments 344 and 345 of the Kaynaklar Forest Management Chiefship within the boundaries of the semi-arid İzmir Forestry Directorate, İzmir Forestry Regional Directorate. The site is within the borders of the Belenbaşı Neighborhood in the Buca District of İzmir Province (Figure 1). The experimental sites are located adjacent to each other. Due to its maritime influence, Izmir Province exhibits a typical Mediterranean climate, characterized by hot, dry summers and relatively rainy winters, with mean long-term temperatures and precipitation levels of 18°C and 697 mm, respectively (AFAD, 2025; MGM, 2025). Drought is a critical factor in the area. The province is characterized as sub-humid by the Erinç Climate Classification (Precipitation Effectiveness Index: 30.14), whereas it is categorized as semi-arid by the Aydeniz Climate Classification (Drought Index: 0.84). Only 20% of the annual average precipitation occurs from April 1 to October 15. Summer precipitation accounts for just 9% of the mean annual precipitation. Having the same climate classification, the Buca district's mean annual temperature and precipitation are 18°C and 692 mm, respectively. (AFAD, 2025; MGM, 2025)The afforestation site has northern to southern aspects. Its elevation varies between 303 and 421 m asl. The site lies on a middle slope with 5-35% slopes. It has loamy and clayey loam soil, with soil acidity varying between 8 and 8.7.

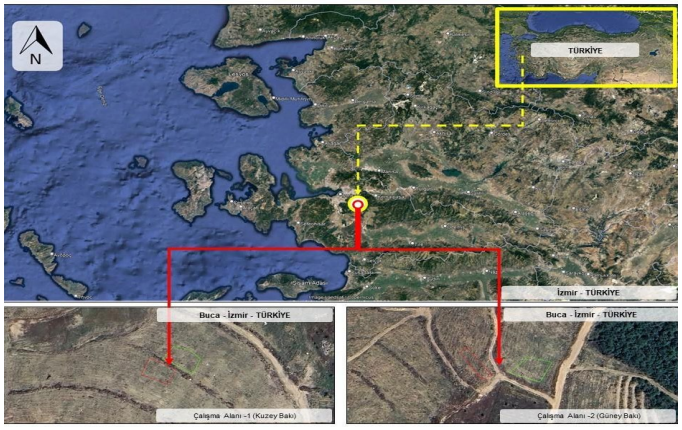

Figure 1. The afforestation site where one-year-old Turkish red pine (*Pinus brutia* Ten.) and maritime pine (*Pinus pinaster* Aiton) seedlings were planted in Izmir-Buca, Türkiye.

Site preparations were carried out in the afforestation area in 2022. One-year-old bare-rooted TRP seedlings (the origin TB-23) and MP (the origin TM-188) were planted with a planting spacing of 3 m x 2 m in the autumn of 2022. Weeding and hoeing were regularly carried out around the seedlings on the site.

A factorial (species and aspect) completely randomized block design with three replications was used for each pine species (i.e., three replications of TRP or MP on the southern aspect and the northern aspect). There were 10 pine seedlings in each experimental unit. In the study, the survival percentages of the seedlings were determined one (September 2023) and two years (November 2024) after planting in the experimental units. The seedlings' root collar diameter (RCD, mm) was measured with a precision mechanical diameter caliper. In addition, the seedlings' height (mm) and crown diameter (mm) were measured with a meter. The mean crown diameter was then determined by averaging diameters measured in the north-south and east-west directions. Afterward, the seedlings' vigor index (height/diameter) was determined. According to the vigor index classification, seedlings with a vigor index value below 50 are considered good seedlings, those between 50 and 60 are considered medium seedlings, and those above 60 are considered deficient (Aldhous, 1994). The results were analyzed using a two-factor (species and aspect) analysis of variance (ANOVA). Tukey's mean separation test was used to distinguish between treatment means. The assumptions of ANOVA were tested, and transformations were applied as needed for the mean separation of the relevant variables. Actual values were used in the tables. ANOVA results were deemed significant at a threshold of $p \leq 0.5$.

3. Results and Discussion

3.1. One year after planting

No mortality was detected in TRP and MP seedlings one year after planting (YAP). The main factors of aspect and species were significant in the analyses regarding seedling growth variables. For pine species, the average diameter, height, and vigor index of TRP were significantly superior to the average diameter, height, and vigor index of MP. TRP's mean diameter, height, and vigor were 12, 35, and 20% higher than the mean diameter, height, and vigor indicators of MP, respectively (Table 1). There was no significant difference between the two pine species regarding seedling crown diameter. Regardless of the species, pine seedlings planted on the north aspect reached 20% more crown diameter

than those planted in the south aspect, with a significant difference (Table 2). There were no significant differences between other growth variables in terms of aspect.

Table 1. Mean root-collar (RCD) diameter, height, vigor index (height/diameter), and crown diameter of Turkish red pine and maritime pine seedlings planted in the afforestation area in İzmir-Buca, İzmir, Türkiye one year after planting, and standard errors.

Species[1]	RCD (mm)	Height (cm)	Vigor Index (mm/mm)	Crown Diameter (mm)
TRP	6.8 a[2] (±1.0)	24.3 a[2,3] (±0.9)	36.2 a[2,3] (±1.0)	146.2 a[2,4] (±4.5)
MP	6.1 b (±0.2)	17.9 b (±0.8)	30.1 b (±1.1)	157.7 a (±5.6)

[1] The species main factor was significant ($p \leq 0.05$) based on ANOVA
2 Means within each column with different letters are significantly different ($p \leq 0.05$)
3 Square-root transformed values were employed for mean separation of this variable
[4] Log-transformed values were employed for mean separation of this variable

Table 2. Mean root-collar diameter, height, vigor index, and crown diameter of Turkish red pine (top) and maritime pine (bottom) seedlings planted on different aspects in the afforestation site located in İzmir-Buca, Türkiye one year after planting and standard errors.

Aspect[1]	RCD (mm)	Height (cm)	Vigor Index (mm/mm)	Crown Diameter (mm)
North	6.6 a[2] (±0.2)	21.9[2] a (±0.8)	33.6 a[2] (±1.0)	163.2 a[2] (±5.7)
South	6.2 a (±0.2)	20.3 a (±1.0)	32.8 a (±1.3)	140.7 b (±4.0)

1 The aspect main factor was significant ($p \leq 0.05$) based on ANOVA
2 Means within each column with different letters are significantly different ($p \leq 0.05$)

3.2. Two years after planting

TRP seedling survival exhibited a small reduction, whereas almost half of the total MP seedlings were killed in 2024 (Table 3). This was most likely due to the extremely challenging weather conditions of 2024. The 2024 spring and summer were particularly challenging, concerning extreme temperatures, drought, and forest fires in Izmir. Mean annual temperature and total precipitation were 19.9°C and 542 mm, respectively. Precipitation levels dramatically declined by almost 50% between April and October 2024, totaling 91 mm instead of the long-term mean annual of 139 mm (AFAD, 2025; MGM, 2025). Similar conditions were observed for the Buca district: A 60% reduction (149 mm) occurred between April and October 2024, when compared to total precipitation (379 mm) for 2024 (MGM, 2025).

The main factor of the aspect and aspect x species interaction term did not show a significant difference in terms of seedling survival rate (Table 3). However, a significant difference was found in terms of species. TRP seedlings showed a 72% higher survival rate compared to MP pine seedlings. When the seedling growth data were analyzed, the main factor of species and species x aspect interaction terms were significant (Table 4). The main effect of species for mean seedling height was also significant. There were no significant differences between different species and aspects in terms of seedling vigor. Only the crown diameter showed a significant difference between the two aspects, regardless of species: saplings planted in the north aspect reached an average crown diameter 26% higher than those planted in the south aspect (Table 5).

Table 3. The effect of species (top) and aspect (bottom) on the mean survival rate of Turkish red pine and maritime pine seedlings planted in the afforestation site located in İzmir-Buca, Türkiye, two years after planting and standard errors.

Factor[1]	Survival Rate (%)
Species	
TRP	91.7 a[2] (±3.7)
MP	53.3 b (±6.7)
Aspect	
South	73.3 a (±10.5)
North	71.7 a (±9.5

[1] The species main factor was significant *(p≤0.05)* based on ANOVA

[2] Means within each cell with different letters are significantly different *(p≤0.05)*

Table 4. Mean root-collar diameter (RCD), height, vigor (height/diameter), and crown diameter of Turkish red pine and maritime pine seedlings planted at different aspects in the afforestation area located in İzmir-Buca, Türkiye, two years after planting, and standard errors.

Species[1]	RCD (mm)	Height (cm)	Vigor Index (mm/mm)	Crown Diameter (mm)
TRP	9.4 a[2,3] (±0.3)	37.5 a[3] (±1.3)	40.1 a (±0.9)	235.5 a (±8.7)
MP	8.3 b (±0.4)	32.8 b (±2.3)	39.5 a (±1.9)	218.4 a (±15.1)

[1] The species main factor was significant (p≤0.05) based on ANOVA
2 Means within each column with different letters are significantly different (p≤0.05)
3 Square-root transformed values were employed for mean separation of this variable

Table 5. Mean root-collar diameter (RCD), height, vigor (height/diameter), and crown diameter of Turkish red pine and maritime pine seedlings planted at different aspects in the afforestation area located in İzmir-Buca, Türkiye, two years after planting, and standard errors.

Aspect[1]	RCD (mm)	Height (mm)	Vigor Index	Crown Diameter (mm)
North	8.9 a[2,3] (±0.3)	360.7[3] a (±15.8)	40.5 a (±1.1)	256.0 a (±9.5)

South	9.1 a (±0.4)	355.8 a (±18.2)	39.3 a (±1.4)	203.9 b (±11.0)

[1] The aspect main factor was significant *(p≤0.05)* based on ANOVA

[2] Means within each column with different letters are significantly different *(p≤0.05)*

[3] Square-root transformed values were employed for mean separation of this variable

Based on this significant species x aspect interaction, the mean seedling diameters of the two pines were separately analyzed by aspect. TRP and MP showed different growth patterns in the north and south aspects: While TRP had a similar diameter growth in both aspects, MP had a significantly lower growth performance (18%) in the south aspect (Table 6).

Table 6. Mean root-collar diameter (RCD) of Turkish red pine (top) and maritime pine (bottom) seedlings planted in the afforestation area in İzmir-Buca, Türkiye, two years after planting according to different aspects

Aspect[1]	RCD (mm)
TRP	
South	10.0 a[2,3] (±0.5)
North	8.8 a (±0.3)
MP	
North	9.2 a[4] (±0.4)
South	7.5 b (±0.7)

1 The species x aspect interaction was significant (p≤0.05) based on ANOVA
2 Means within each column with different letters are significantly different (p≤0.05)
3 Square-root transformed values were employed for mean separation of this variable
4 Log-transformed values were employed for mean separation of this variable

The significantly higher seedling survival percentage of TRP compared to MP after two years is a striking observation. This is in line with findings indicating the high drought tolerance of TRP. This pine species has shown a significant advantage over MP in the semi-arid conditions of the study site (Boydak, 2004; Kavgacı et al., 2016; Baykara & Eşen, 2024). Fernandes and Rigolot (2007) point out that climate change increases the risk for this species due to changes in fire regime. This difference underlines the important role of species selection in afforestation in water-scarce environments (Boydak, 2004; Kavgacı et al., 2016; Baykara and Eşen, 2024).

The important influence of aspect, especially on diameter and crown diameter, should be carefully considered. The superior growth observed on north-facing slopes probably reflects better soil moisture retention due to reduced solar radiation and total evaporation, a factor well documented in the literature (Shiver et al., 1990; Karamanoli et al., 2017). The statistically significant interaction between species and slope highlights potential species-specific responses to microclimatic variability, particularly for MP diameter growth.

Regardless of species, seedlings' 26% greater crown diameter on north-facing slopes underscores the importance of microclimate optimization in afforestation practices.

The findings strongly suggest that TRP is a more suitable species for afforestation in semi-arid climates, significantly when drought is projected to intensify under climate change (Demircan et al., 2017; Bağçacı et al., 2021). Its high survival and, in some respects, growth characteristics, combined with its known adaptability to harsh conditions (Boydak, 2004), support the case for its selection for future afforestation projects. While MP exhibits acceptable growth under certain conditions (especially on north-facing slopes), the resilience of TRP makes it a more reliable option for long-term success in water-limited environments.

The study was confined to a two-year observation period and a single location. While this allows for focused research, long-term monitoring is essential to assess these afforestation efforts' long-term performance and sustainability. Further research involving a wider range of sites and more extended observation periods would improve the generalizability of the findings. TRP and MP are two pine species with a wide horizontal distribution and, thus, a wide range of growing environments, offering a wide range of provenance options for drought tolerance (Gaspar et al., 2013; Kandemir et al., 2017). Therefore, it would be helpful to link the genetic variability of these two species to climate change adaptation and mitigation performance in future studies. It would also be helpful to conduct soil analyses in future studies to investigate other soil properties that may affect growth differences between species and at different elevations.

4. Conclusion and Implications

This study investigated the early performance of red pine and maritime pine plantations in a semi-arid region of Izmir-Buca, Türkiye, focusing on survival rates and growth of planted seedlings over two years. It also addressed a critical issue of species selection for afforestation in semi-arid regions facing climate change. The results revealed significant differences in sapling survival rates and growth, emphasizing the critical role of species selection for successful afforestation in these environments. The significantly higher survival rate of Turkish red pine strongly suggests the higher drought resilience of this species. This finding aligns with research showing that Turkish red pine adapts to challenging environmental conditions such as drought. Growth analysis showed significant effects of aspect, with better seedling initial performance on north-facing slopes due to better soil moisture economy, which is also confirmed by existing literature. When the current climate data is compared with the long-term climate data of Izmir (see Sections 2. and 3.2.),

it shows that the region has entered a significantly longer, drier period. The findings of the present study strongly suggest that Turkish red pine is a more suitable species for afforestation in semi-arid regions, considering that drought's frequency, severity, and impact will increase with climate change. Turkish red pine's drought tolerance might affect its long-term growth and resilience to other stressors (e.g., pests, diseases). Forest managers should therefore prioritize Turkish red pine over maritime pine in future afforestation projects. Results can be generalized to other Mediterranean regions with similar climate (i.e., semi-arid) conditions However, confirming similar studies in different growing environments and using different species origins would be helpful, and providing longer-term data by correlating the results with soil properties would be beneficial.

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